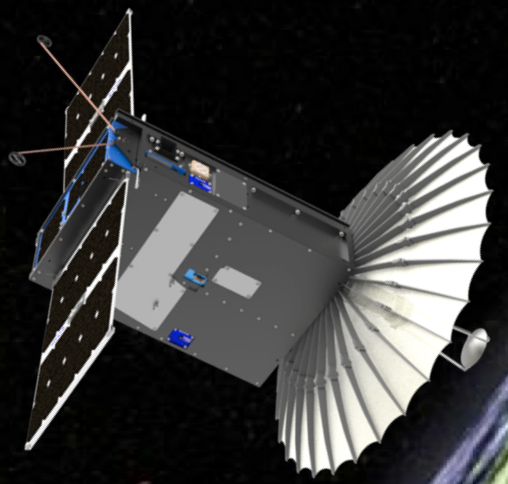
RainCube

Jet Propulsion Laboratory
California Institute of Technology

RainCube - First Ka-Band Precipitation Radar Mission in CubeSat: From Concept To Mission



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Project Scientist – Dr Simone Tanelli
Project Manager – Dr Shannon Statham
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Mission Operations Lead – Chris Shaffer
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NASA – Ames Research Center, CA
June 11 – 13, 2019

RainCube – Radar In a CubeSat

RainCube is a ***technology demonstration*** mission to enable ***Ka-band*** precipitation radar technologies on a low-cost, quick-turnaround platform.

- **SMD's ROSES 2015 InVEST Selection (ESTO) to**
  - Validate new Earth science technologies in space (TRL 4 to TRL 7)
  - Radar in 6U CubeSat, deploy to LEO from ISS
  - Three month primary mission (1 month payload demo/commissioning phase)
- **Two Key Mission Objectives**
  - Demonstrate new technologies in Ka-band on a CubeSat platform
    - Miniaturized Ka-band Atmospheric Radar for CubeSats (miniKaAR-C)
    - Ka-band Radar Parabolic Deployable Antenna (KaRPDA)
  - Enable precipitation profiling radar missions for Earth Science
- **Roles & Responsibilities**
  - NASA ESTO: Sponsor
  - JPL: Project Management, Mission Assurance, Radar Delivery
  - Tyvak: Spacecraft Delivery, System I&T, Mission Operations

Organization Chart

RainCube Program Manager
Eastwood Im / Gary Lau

Principal Investigator
Eva Peral

Principal Scientist
Simone Tanelli

Project Manager
Shannon Statham

Spacecraft Manager
Macon Vining

JPL
Mechanical: J. Sauder
Thermal: J. Kanis, S. Carlson
ACS: K. Lo
Comms: A. Babuscia
MOS/GDS: S. Gibson

Tyvak, Inc.
Manager: A Williams
Systems: R Prasad
Mechanical: J Brown
Thermal: S Yamamoto
ACS: J Bowen
Electrical: J Abel
Software: S Fitzsimmons
AIT: N Fite

Radar Instrument Manager
Eva Peral

Instrument Engineer: D Price
Antenna RF: N Chahat
Antenna Mechanical: J Sauder, T Bailey
Power Electronics: G Cardell, B Wang, D Chi
Electronics RF: D Price, C Parashare
Digital Assembly: M Cruz, S Joshi, B Ortloff, D Wang
Electronics Packaging: G Gaughen, J Cardone

Mission Operations Manager
Shivani Joshi

SC Mission Operations Lead
Chris Shaffer (Tyvak Inc.)

JPL
Science Data Processing: E Peral, S Tanelli, G F Sacco, O Sy
JPL Anomaly Response Team: E Peral, S Tanelli, S Statham, T Imken, N Rouse, J Sauder (Antenna)
Additional Anomaly Resolution support: B Ortloff, D Price, M Cruz

Tyvak, Inc.
Manager: A Williams, T Mosher
Operations Manager: M Villa
SC Operators: K Kawashima, J Price, S Sundin
SC Commissioning support: S Fitzsimmons

Mission Assurance Manager
Carlo Abesamis, Nazilla Rouse

Lead Systems Engineer
Travis Imken

Mission Overview and System Architecture

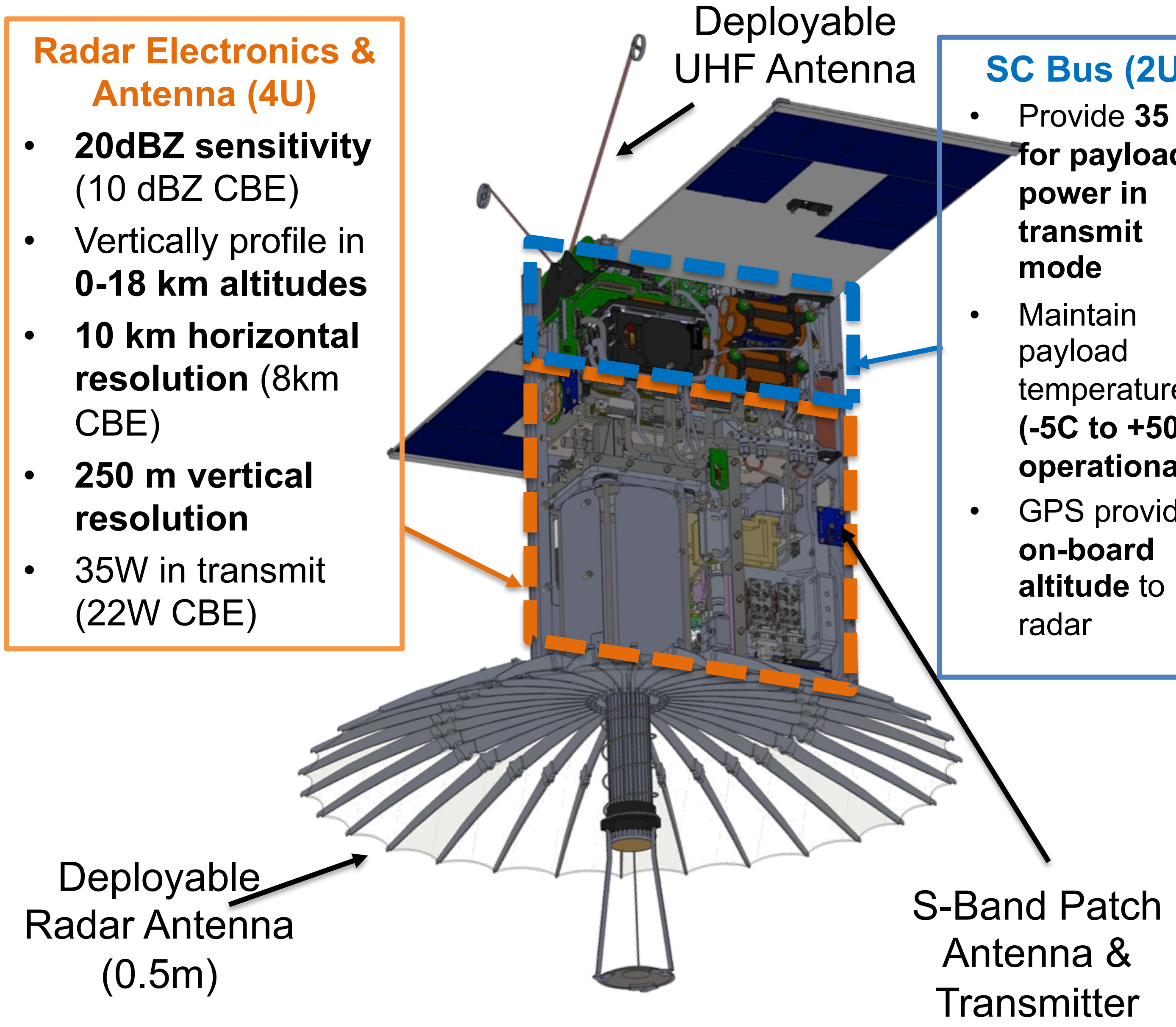
- RainCube's novel radar architecture reduces number of components, power consumption and mass by over an order of magnitude wrt the existing spaceborne radars.

- Operating at 35.75 GHz, RainCube signal can penetrate deep into the layers of a storm.
- Gives verticle profile of reflectivity.

- Paves way for precipitation measurements over smaller time scales to better understand evolution of many weather systems.

Radar Electronics & Antenna (4U)

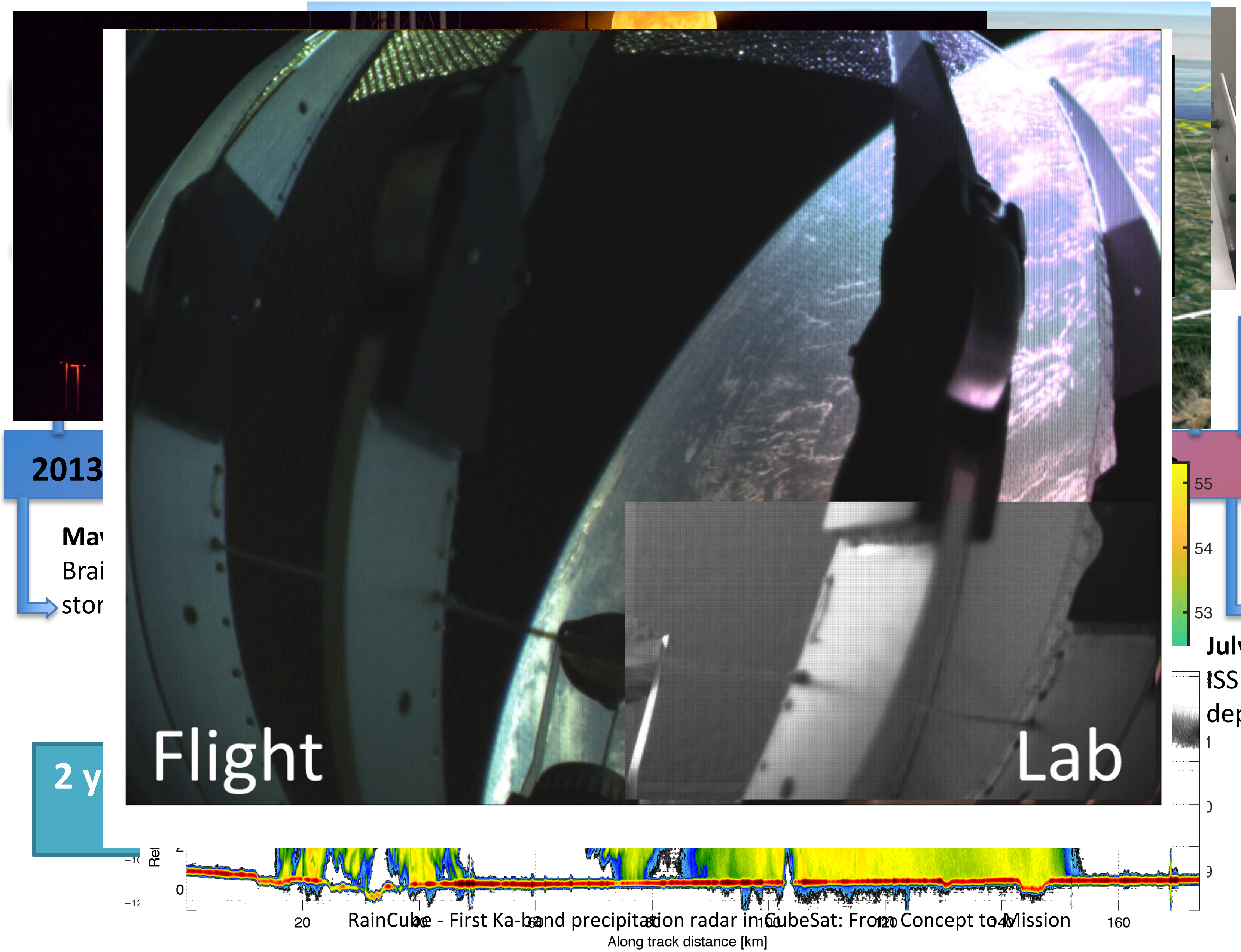
- **20dBZ sensitivity** (10 dBZ CBE)
- Vertically profile in **0-18 km altitudes**
- **10 km horizontal resolution** (8km CBE)
- **250 m vertical resolution**
- 35W in transmit (22W CBE)



SC Bus (2U)

- Provide **35 W for payload power in transmit mode**
- Maintain payload temperatures **(-5C to +50C operational)**
- GPS provides **on-board altitude** to radar

Timeline from TRL0 to TRL 7



2013

May
Brai
stor

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July 13
ISS
deployment

July 28
Antenna
deployment

Aug 5
First echo

Aug 27
First rain!

Sept ‘18
1st Extended
Mission

Feb ‘19
2nd Extended
Mission

June ‘19
3rd Extended
Mission

RainCube Tx Operation #23 - August 27 , 2018 – 20:14 UTC

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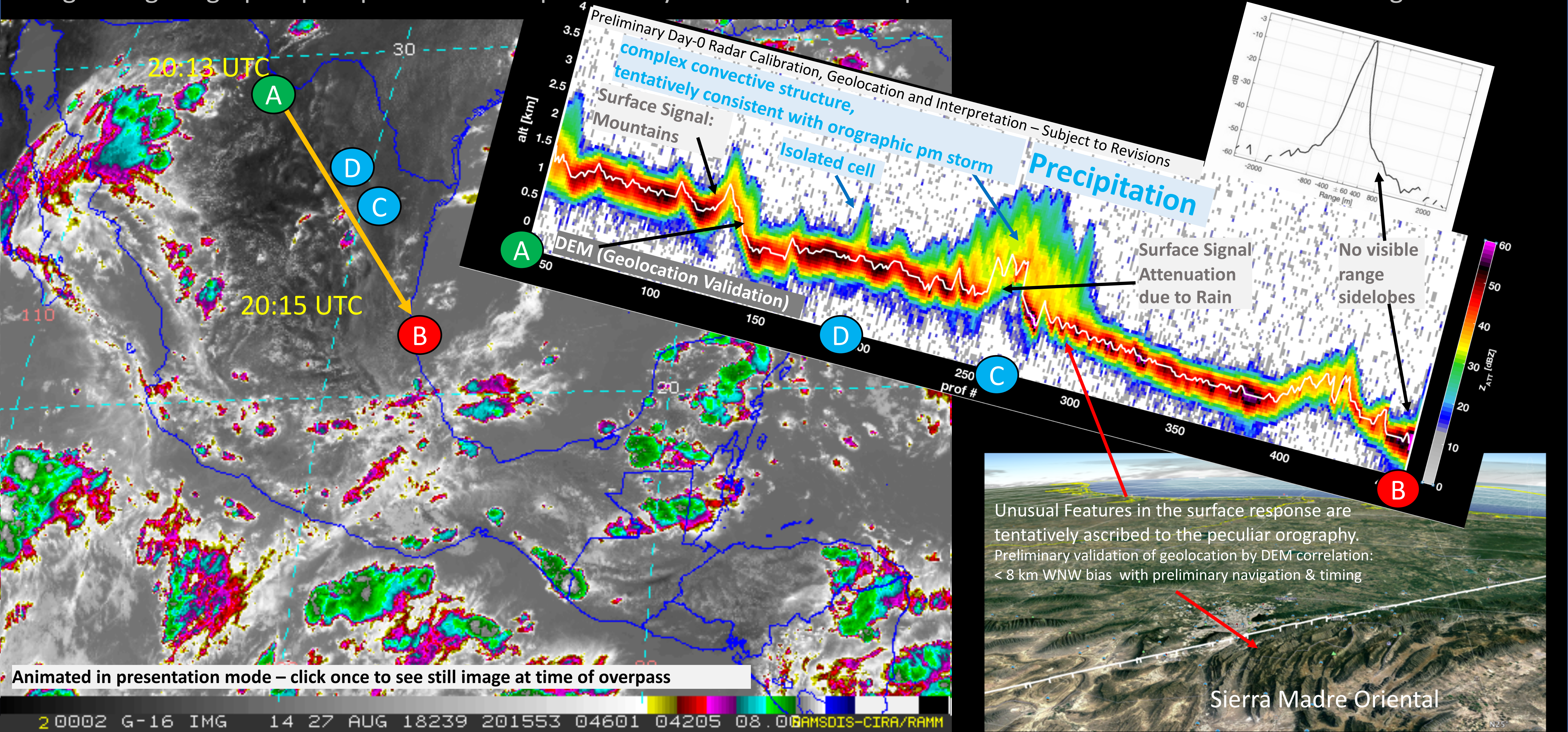
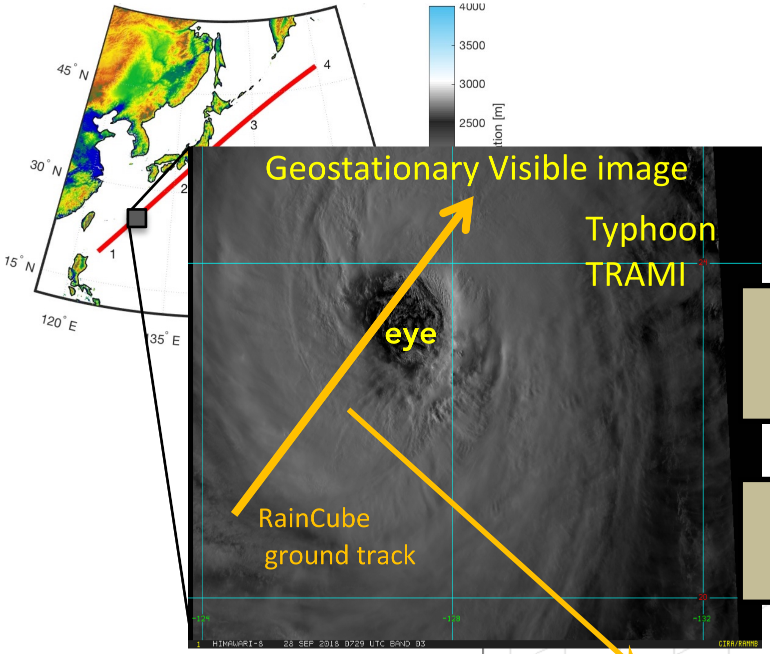
First successful operation in Nadir Pointing & first detection of rain over the Sierra Madre Oriental, near Monterrey, Mexico.
Fast growing orographic precipitation developed shortly before RainCube's pass which overflew its north-eastern edge



RainCube and TEMPEST-D coincidental measurement of Typhoon TRAMI – Sept 28, 2018

- TEMPEST-D and RainCube overflew Typhoon Trami < 5 minutes apart
- RainCube nadir Ka-band reflectivity shown overlaid on TEMPEST-D 165 GHz brightness temperature
- Illustrating complementary nature of these sensors in constellation for observing precipitation
- Trami observed shortly after it had weakened from Cat 5 to Cat 2



RainCube
6U Ka-band (35.7GHz) nadir pointing radar

~5 min apart

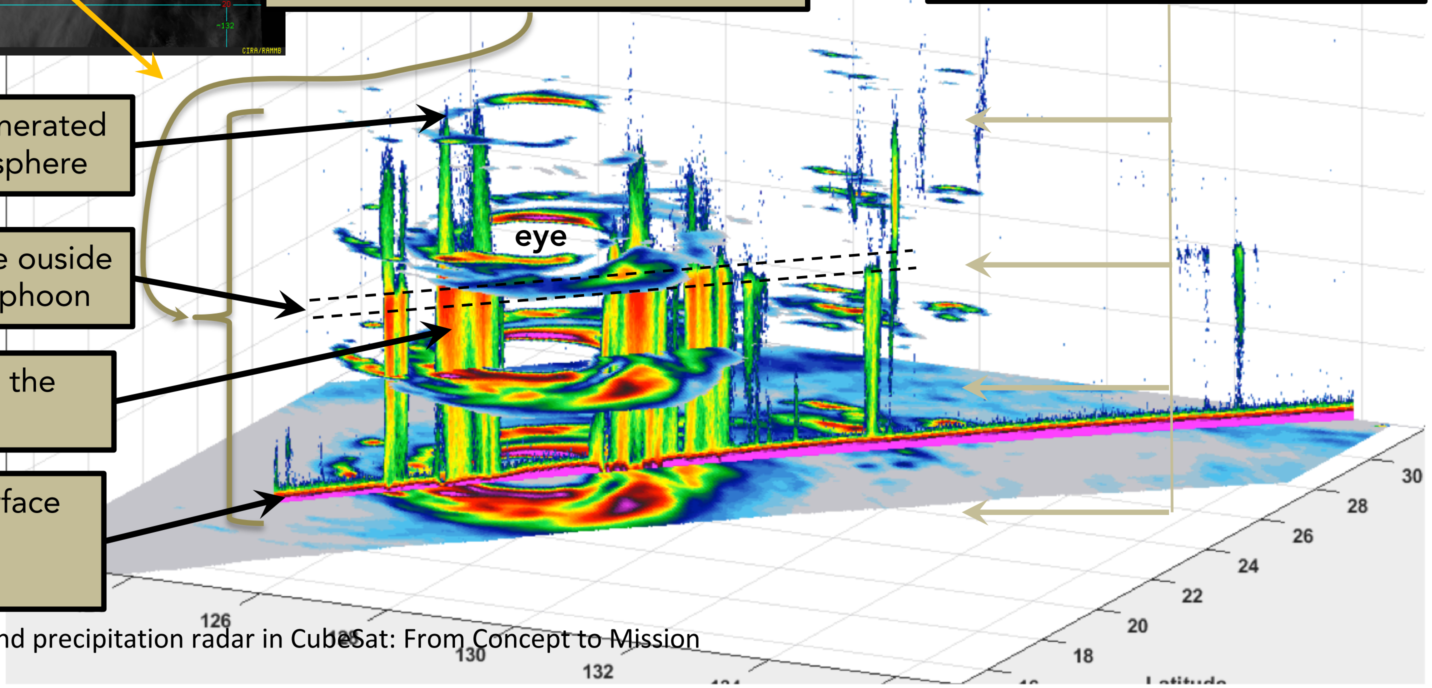
Tempest-D
6U multi-channel microwave radiometer

Novel ultra compact architecture, high performance pulse compression

Novel ultra compact architecture, high quality calibration

1D Horizontal structure, 250 m vertical resolution

2D Horizontal structure, 4 vertical levels



Extent of penetration of ice generated by convection in upper troposphere

Melting Layer : ~4.8 km altitude ouside of TRAMI, raised inside the Typhoon

Intensity of precipitation in the eyewall and rainbands

Strong echo from ocean surface does not contaminate precipitation echo

Slide Credit –
Shannon Brown (TEMPEST-D),
Simone Tanelli (RainCube)

After primary mission success, we wanted to target forecasted precipitation and collocated measurements with other missions. In order to improve efficiency of mission operations towards this goal, we increased automation starting with automating the planning of events in a prioritized way

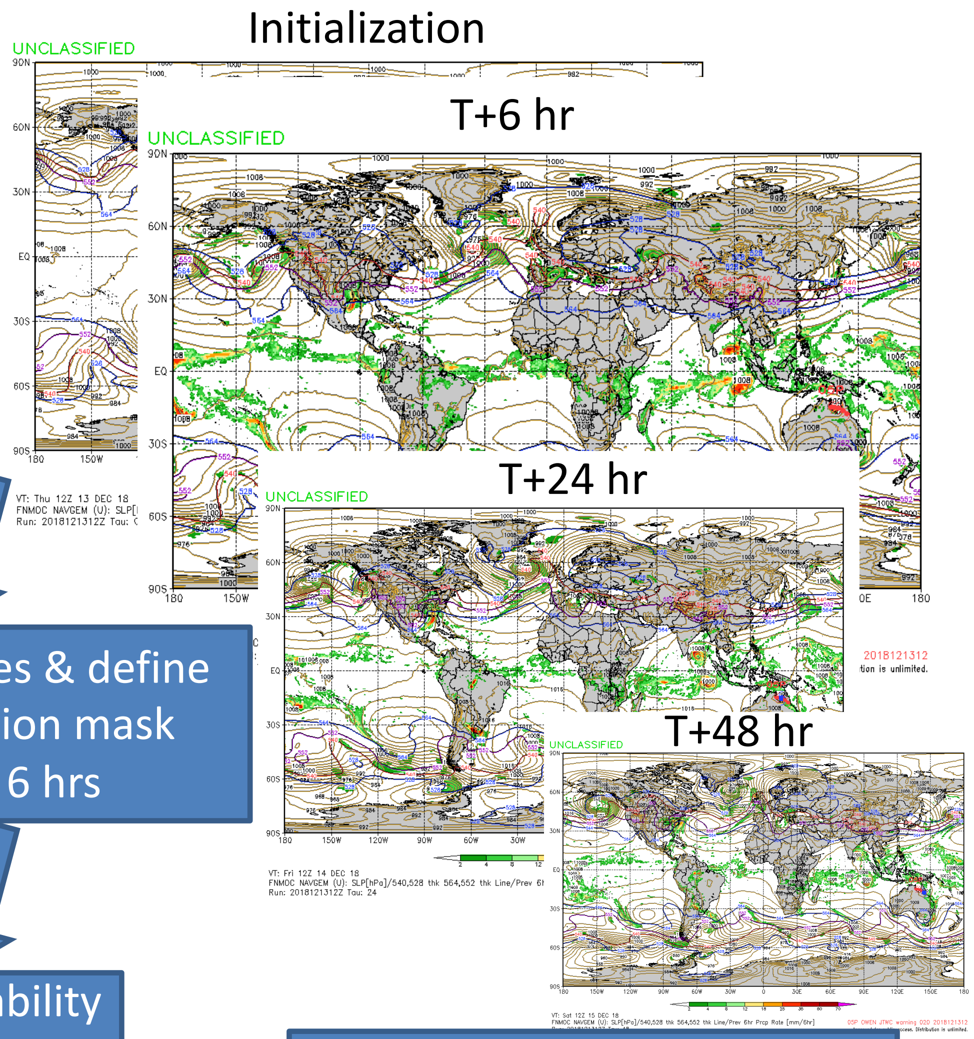
- **Constraints for automation**

a. Maximum of 6 20 minute Radar Acquisitions per day (Imposed by spacecraft power system)

b. No operations on consecutive orbits (Imposed by spacecraft power system)

c. No operations in umbra (Preferred because of higher occurrence of reboots in umbra)

- **Target Priorities**
  - Forecasted presence of precipitation
  - CONUS – for NEXRAD
  - GPM – for DPR
  - Storms of interest



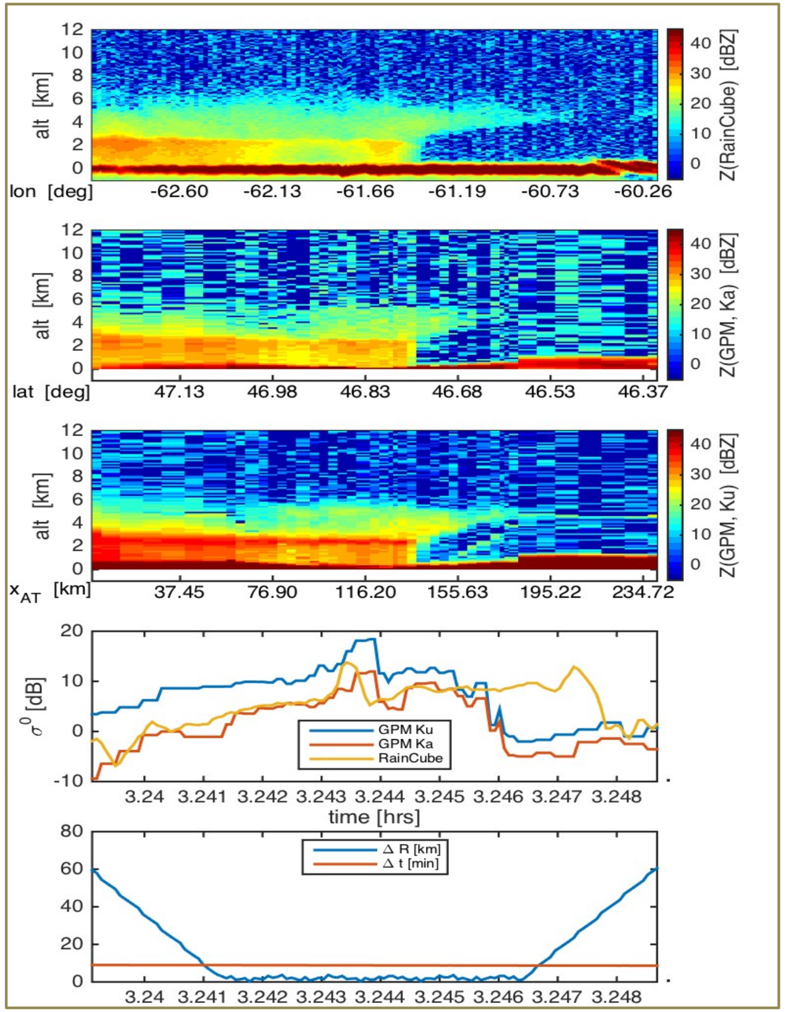
Parse images & define precipitation mask every 6 hrs

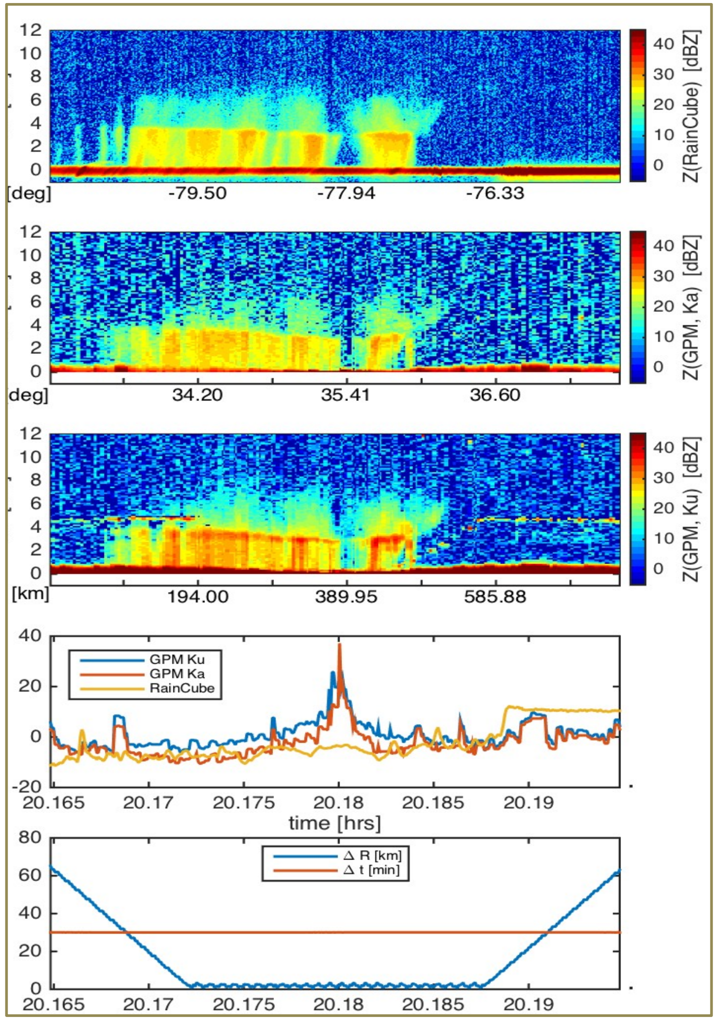
Calculate local probability of precipitation along the predicted orbit of RainCube

Prioritize close approaches with GPM and passes over GPM GV sites (CONUS, Japan, Australia)

RainCube Calibration – GPM/DPR Relative Calibration Validation

- Colocations within margins (50 km horizontally, 30 mins)
- Comparing Raincube observations (Z, σ^0) to Ka-band observations from GPM
- "best comparisons" with persistent stratiform scenes
- Implemented an optimization approach that correlates RainCube's (Z, σ^0) to GPM's





Credit: Ousmane Sy (JPL)

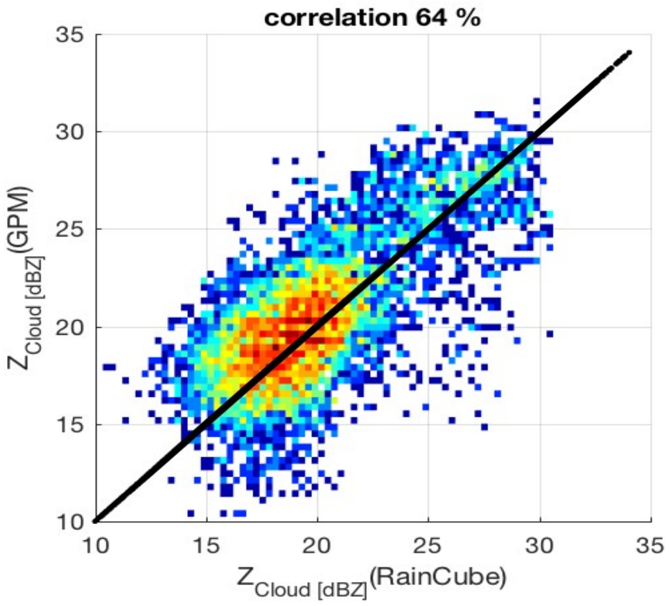
RainCube Calibration – Outcomes

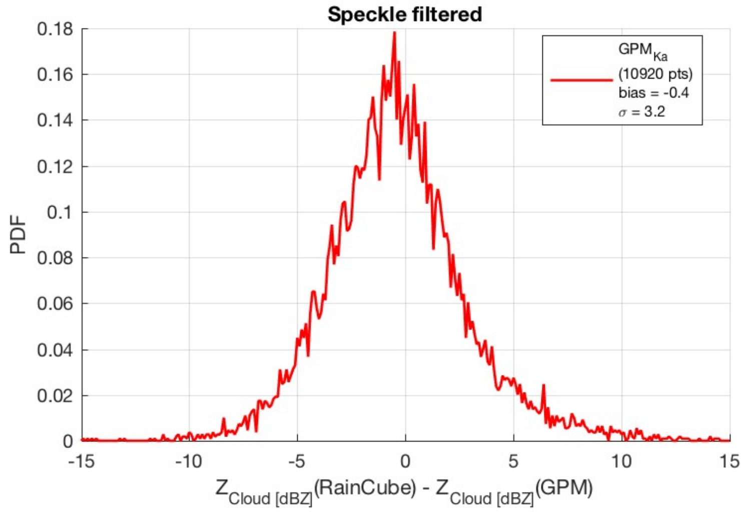
Current estimate of bias between DPR Ka and RainCube.
Two independent approaches indicate :

a) |Bias| < 1.5 dB
b) bias << σ

Outcomes:

1) no calibration correction planned for next public release of science data
2) Inclusion of this assessment in the product document for user awareness





Credit: Ousmane Sy (JPL)

Managing risk and resources

In order to achieve a successful Technology Demonstration with extremely limited resources risk had to be managed in a quite different way (wrt Science Missions).

- Two primary principles guided the development:
  - Meet the demonstration of key enabling technology, with every other objective becoming a best effort
  - Fit in schedule (i.e., meet original CSLI launch opportunity) and budget (no reserves and little tolerance for cost growth).
- All ”tough” decisions were driven by these two criteria. With conscious acceptance of risk posture.
  - Some of the risks were realized during I&T
    - Some of them could be resolved within the limited time and budget.
    - Some of them were accepted.
  - Some of the risks were realized in orbit
    - Some of them could have been mission ending, and were resolved.
    - Others just limit the operational capability and achieving some of the higher order requirements.
      - Excellent opportunity to develop and demonstrate workarounds.

Anomaly description	Root cause and Resolution
Aperiodic system level reboots	Never seen before, root cause hypothesized but not verified. No known resolution. Major motivation to collect radar measurements over targets of interest.
Failure of 1 of two MPPTs – Peak Power Tracker	Known issue with SC solar panel configurations and known risk at the time of delivery to NanoRacks. Mission is operating at half its power capacity. Major motivation to operate radar over smaller bursts of targeted collections. Requires careful planning of operations.
Bad pulse shape	Observed occasionally during radar I&T. Deemed resolved but observed again in flight. Resolved by implementing special initialization sequence. Proves importance of EGSE flat-sat and configuration control.
Z-RWA (Failure of Z-axis Reaction Wheel)	One hypothesized root cause but not verified. Attempts to recover the wheel deemed unfruitful. Ops and GNC teams devised novel methods to operate radar using 2 RWs or 3 TRs without modifying the core ADCS algorithm and flight software. As an interesting development since occurrence of this anomaly – the system level reboots reduced from many a day to one in many days.
SD card failure	Observed on other missions. Can be resolved by reformatting while the card is rendered read only. If data is not read and card reformatted in timely manner, the card can completely fail causing loss of science data.

Lessons Learned

1. Extended Formulation Phase
2. Tailored versions of NASA and Institutional Flight Practices
3. Clearly define roles and responsibilities of each organization at the time of contract formation
4. 6U form factor is useful for standardized dispenser and tech demo but consider larger form factor for ease of cable and thermal design
5. Revise flight mass growth contingency for CubeSat and SmallSat missions – the 5-30% margin reserved for flight missions is too strict for CubeSats
6. Value of pre-operations ORT aka Rehearsal
7. Value of Anomaly Response Team during commissioning
8. Value of excellent EGSE flat-sat for both radar and SC
9. Prioritized mission objectives well beyond primary objectives

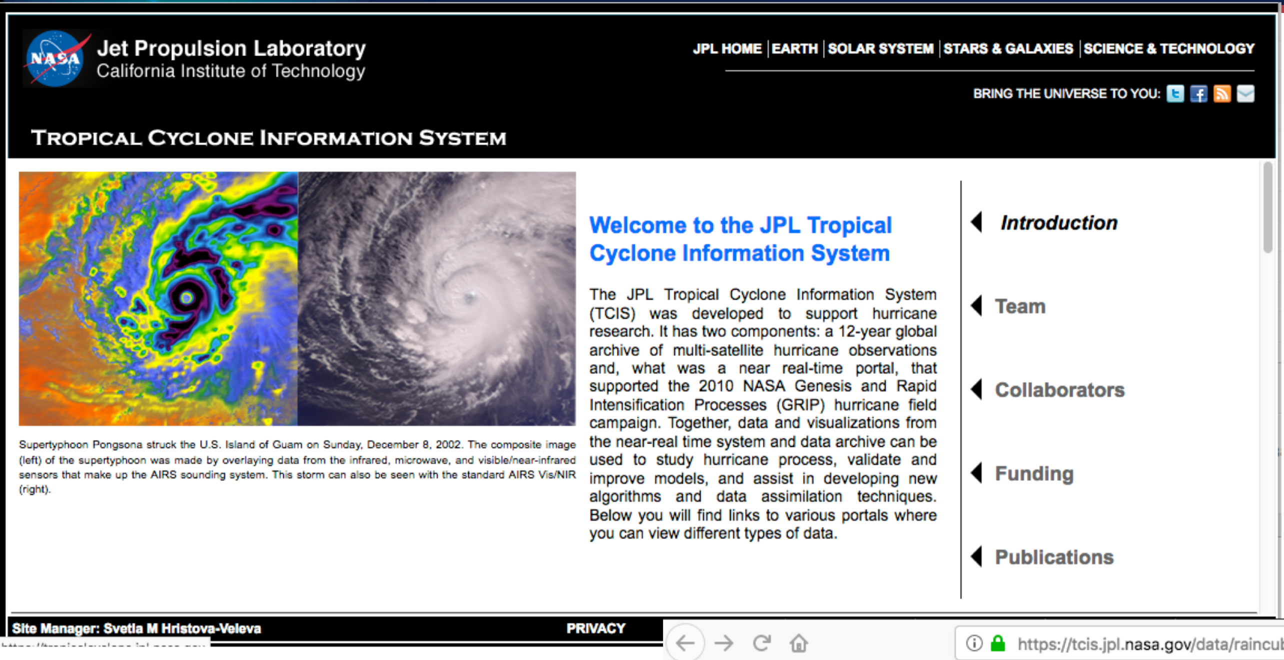
What's Next?

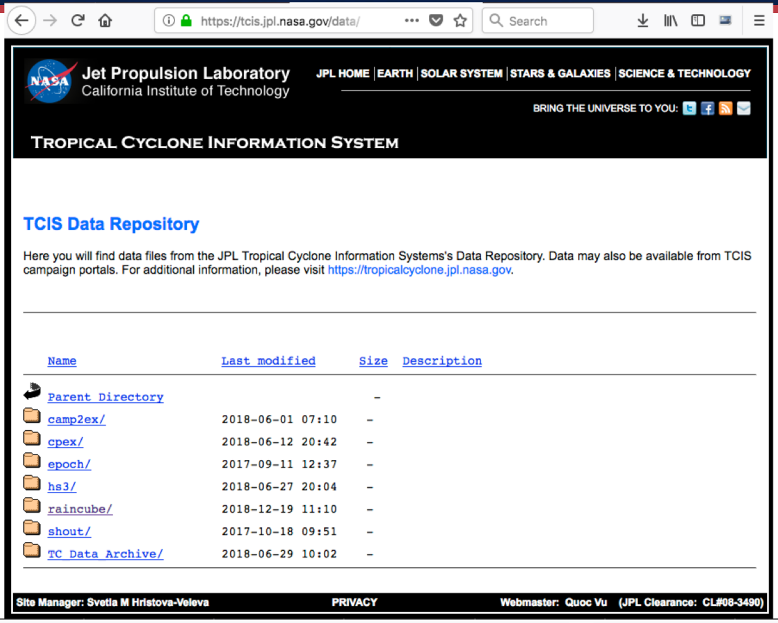
- Constellation of RainCube's "as is"
  - Analyze the current dataset to demonstrate the potential and the limitations of the current system in addressing specific science questions.
- Constellation with a larger/scanning antenna
  - To address a larger set of science questions
  - Development of technologies and of mission concepts is ongoing
- Constellation with other Radars and Radiometers:
  - A study team in the Earth Science Decadal Survey 2017 will consider RainCube-like constellations for measurements of convection and precipitation
  - Higher frequency versions of RainCube for cloud and water vapor observations
- Planetary applications
  - An evolution of this instrument could support altimetry and cloud and precipitation on planetary targets

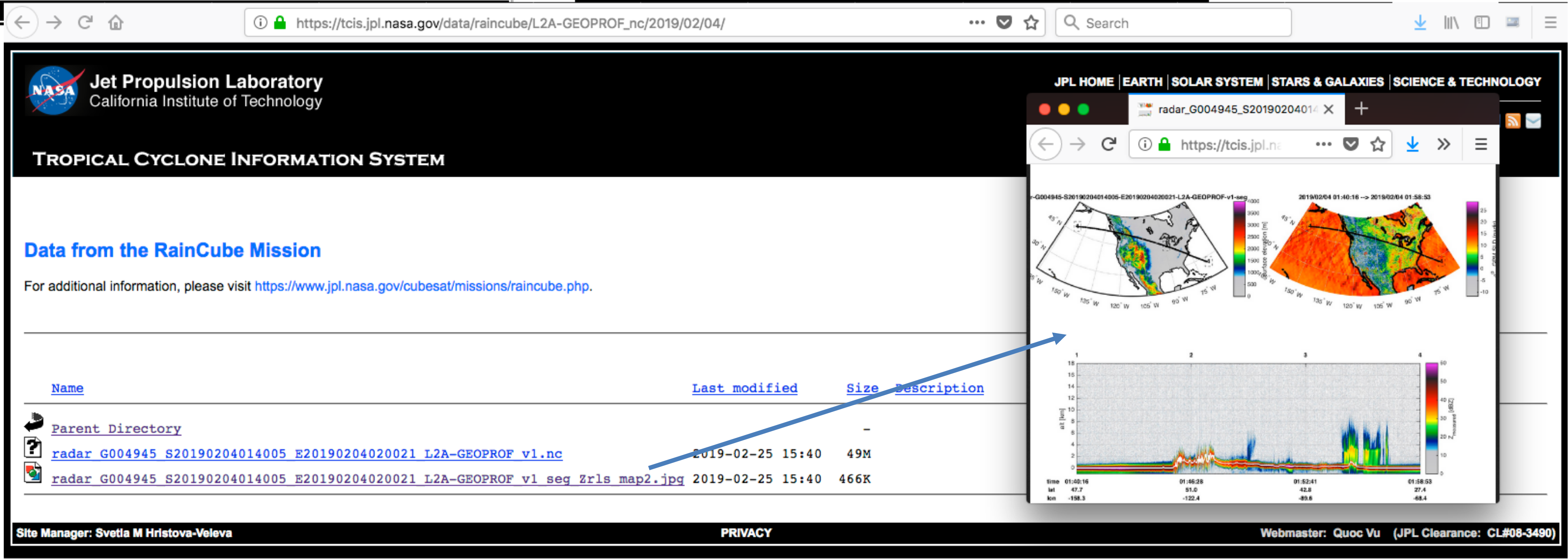
Ka-band ESTO InVEST and ACT programs

	6U	12 U	50 kg
Antenna size [m]	0.5	1.0	2.0
Sensitivity [dBZ]	15	5-10	0-5
Hor Resolution [km]	8	4	2
Range Res [m]	250		
Beams	1	1-3	1-5
RF Power [W]	10	10-20	10-40

TCIS portal hosts RainCube data







The Tropical Cyclone Information System hosts RainCube data. Huge thank you to PI : Svetla Hristova-Veleva, Site Administrator Quoc Vu, and Data Manager Brian Knosp)

L2A are posted (data & browse images).
L2B Data will be made public when QC is satisfactory.
No plan to open L0 and L1 data to the public.

You can now follow RainCube on NASA's Eyes

https://go.nasa.gov/2PGdBus


NASA
Jet Propulsion Laboratory
California Institute of Technology
RainCube Project Team
February, 2017
RainCube
RADAR FOR RAIN PROFILING
CubeSats
RainCube
EXIT
RAINCUBE